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LIDAR optical rugosity of coral reefs in Biscayne National Park, Florida

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Abstract The NASA Experimental Advanced Airborne Research Lidar (EAARL), a temporal waveform-resolving, airborne, green wavelength LIDAR (light detection and ranging), is designed to measure the sub-meter-scale topography of shallow reef substrates. Topographic variability is a prime component of habitat complexity, an ecological factor that both expresses and controls the abundance and distribution of many reef organisms. Following the acquisition of EAARL coverage over both mid-platform patch reefs and shelf-margin bank reefs within Biscayne National Park in August 2002, EAARL-based optical indices of topographic variability were evaluated at 15 patch reef and bank reef sites. Several sites were selected to match reefs previously evaluated in situ along underwater video and belt transects. The analysis used large populations of submarine topographic transects derived from the examination of closely spaced laser spot reflections along LIDAR raster scans. At all 15 sites, each LIDAR transect was evaluated separately to determine optical rugosity (Ro_{tran}), and the average elevation difference between adjacent points ($Av(\delta E_{ap})$). Further, the *whole-site* mean and maximum values of Ro_{tran} and $Av(\delta E_{ap})$ for the entire population of transects at each analysis site, along with their standard deviations, were calculated. This study revealed that the greater habitat complexity of inshore patch reefs versus outer bank reefs results in relative differences in topographic complexity that can be discerned in the laser returns. Accordingly, LIDAR sensing of optical rugosity is proposed as a complementary new technique for the rapid assessment of shallow coral reefs.

Keywords Aircraft remote sensing · LIDAR · Rugosity · Monitoring · Florida Keys

Introduction

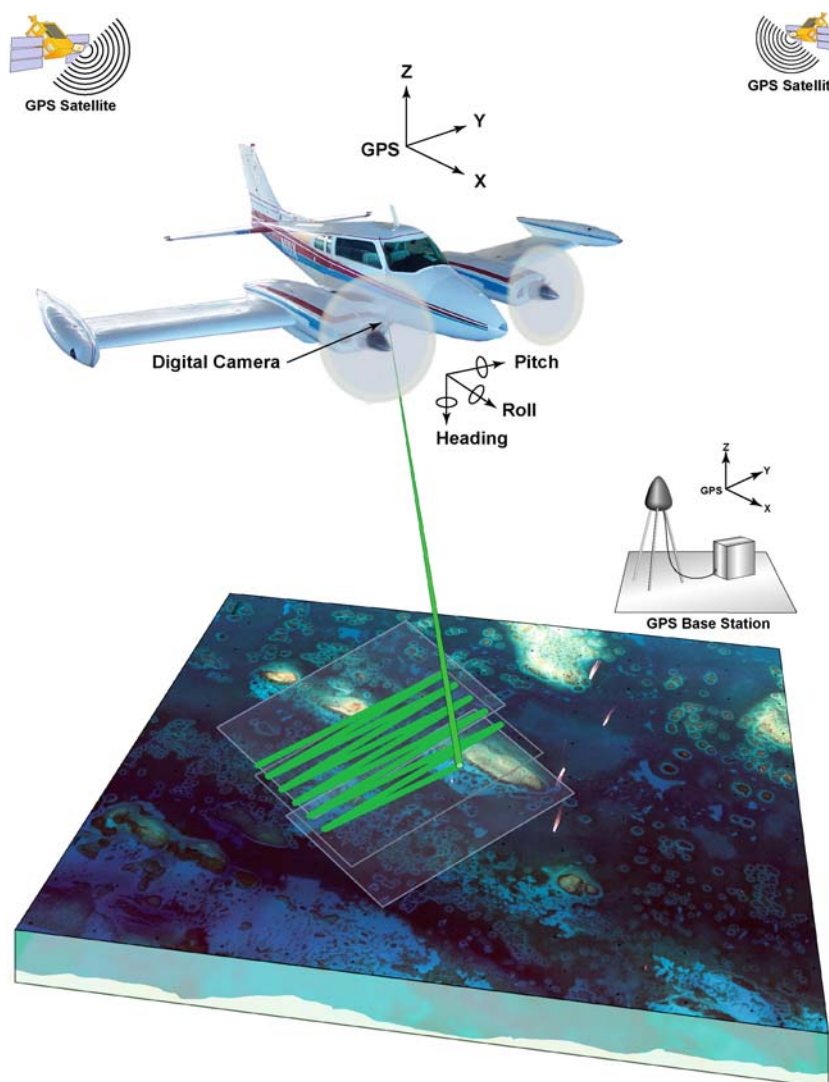
Variability in vertical relief, or rugosity, is a significant aspect of habitat complexity, a factor that both reflects and governs the spatial distribution and density of many reef organisms (Sale 1991; Sebens 1991; McCormick 1994). Topographic complexity on coral reefs is typically assessed along rugosity transects as the ratio of the horizontal distance crossed by a chain laid upon the reef surface contour to the linear horizontal distance between the two endpoints (Aronson et al. 1994; Rogers et al. 1994). Rugosity surveys are useful in studies of reef ecological structure and function (Sebens 1991; McCormick 1994; Szmant 1997), catastrophic change due to hurricane impacts and ship groundings (Rogers et al. 1982; Rogers and Miller 2001), long-term cumulative disturbance or bioerosion (Sebens 1991; Aronson et al. 1994), fish assemblage structure (Sale 1991; Hixon and Beets 1993; Friedlander and Parrish 1998), and associated conservation value (Chapman and Kramer 1999; Edinger and Risk 2000).

Most optical remote-sensing investigations of coral reefs involve the use of *passive* techniques that rely upon reflected sunlight (Mazel 1999). This class of remote sensing can be used to survey coarse bathymetry (Lyzenga 1978; Sandidge and Holyer 1998), but cannot capture the fine-scale morphology that is evaluated by measuring rugosity transects across reefs. An *active* remote-sensing approach utilizing a laser light source provides greater promise for sounding the detailed topography of shallow coral reefs. The LIDAR (light detection and ranging) altimeter deployed in this investigation is the Experimental Advanced Airborne Research Lidar (EAARL), a temporal waveform-resolving, green laser altimeter constructed at NASA

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Fig. 1 The NASA Experimental Advanced Airborne Research Lidar (EAARL). Geolocation information is provided by kinematic differential GPS. Digital aerial photography is collected coincident with the laser scans



by one of the authors (C.W. Wright; Fig. 1). The first NASA EAARL surveys of a coral reef tract were carried out in the northern Florida Keys during the summers of 2001 and 2002, in parallel with in situ optical measurements and benthic cover assessments by SCUBA divers.

The goal of this study is to examine the capability of a temporal waveform-resolving, airborne green LIDAR to retrieve ecologically meaningful morphological information over shallow coral reef substrates. The specific objectives of this paper are to:

1. Describe the lineage and design of the EAARL, a new type of airborne LIDAR instrument that has capabilities for surveying the submeter-scale topographic complexity of shallow coral reefs.
2. Demonstrate the capability of small-footprint, temporal waveform-resolving, airborne green LIDAR to optically sense rugosity variation between reefs in Biscayne National Park (BNP) that are known to vary in habitat complexity.

Conclusions

Optical rugosity analysis revealed variation in whole-site measures of LIDAR-sensed topographic complexity that matches previous in-situ qualitative and belt-transect assessments of the relative habitat complexity of bank reefs and patch reefs in the study area. The EAARL measured higher whole-site optical indices of topographic variability at patch reefs relative to bank reefs, which was consistent with field observations of higher stony coral cover, octocoral cover, and coral species richness on patch reefs relative to the rubble-dominated bank reefs within the study area. Since LIDAR optical rugosity measurements clearly reflected key benthic parameters, it has potential application as a monitoring tool capable of detecting changes in reefs over large areas.